Early stages of wind wave and drift current generation under non-stationary wind conditions

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The generation and amplification mechanisms of ocean waves are well understood under a constant wind speed or in limited fetch conditions. Under these situations, the momentum and energy transfers from the air to the water are also quite well known. Many studies have been done to characterize the balance of the transfers between the generation of the surface drift current and the waves. However during the wind field evolution over the ocean, we may observe sometime high acceleration/deceleration situations of the wind velocity (e.g. Mexican Tehuano or Mediterranean Mistral wind systems). Under these non-stationary situations the evolution of wave systems is not well understood.

For this reason we carried on laboratory experiments in a wave tank where it was possible to control and modify fast evolutions of wind velocity. The purpose of these experiments was to better understand the early stages of the generation of water-waves and surface-drift currents under non-stationary wind conditions and to better know the balance between the transfers that create waves and surface currents during non-equilibrium situations.

The experiments were conducted in the Institut Pythéas wind-wave facility in Marseille-France. The wave tank is 40 m long, 2.7 m wide and 1 m deep. Over the water surface, the air section is 50 m long, 3 m wide and 1.8 m height. We used 11 different resistive wave-gauges located all along the tank. The momentum fluxes in the air column were estimated from single and X hot-film anemometer measurements. The sampling frequency for wind velocity and surface displacement measurements was 256 Hz. Water-current measurements were performed with a profiling Vectrino velocimeter. This device measures the first 3.5 cm of the water column below the surface with a frequency rate of 100Hz, and with a 1 mm vertical sampling. During the experiments, the wind intensity was abruptly increased with a constant acceleration over time, reaching a constant highest intensity of 13 m/s. This constant velocity remains constant during a few minutes, then the intensity was again reduced suddenly with a constant deceleration.

We observed that wind drag coefficient values for accelerated wind periods are lower than the ones reported in previous studies for constant wind speed (Large and Pond 1981; Ocampo-Torres et al. 2010; Smith 1980; Yelland and Taylor 1996). This is probably because the turbulent boundary layer is not completely developed during the increasing-wind sequence. As it was reported in some theoretical studies (Miles 1957; Phillips 1957; Kahma and Donelan 1988), we observed that the wave growth presents a linear tendency in the earliest stage of the accelerated wind period. This is associated to local wind-wave generation. Then, when the wind velocity reaches 2-3 m/s, the wave growth is exponential due to the presence, the evolution and propagation of waves along the tank. The injection energy from wind to currents seems to be a continuous process that starts with the development of the air turbulent boundary layer. The increased surface current intensity is associated to the increased friction wind velocity, u_*. However, the evolution of the waves depends more on the intensity of the wind-acceleration, and therefore on the development stage of air turbulent boundary layer. For lower acceleration experiments, it exists a further development of the air turbulent boundary layer: there is first a downshift of the wave-spectral peak frequency, then this downshift is followed by an increase of the significant wave height. On the other hand, when the acceleration is high, the boundary layer is poorly developed, and the increase of the wave height occurs before the frequency peak downshift. For intermediate wind accelerations, the current and wave evolution occur at the same time.

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